3^{rd} *International Conference on New Developments in Soil Mechanics and Geotechnical Engineering,*
28-30 June 2012, Near East University, Nicosia, North Cyprus

Small strain behavior of Northern Izmir (Turkey) soils

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KEYWORDS: Cyclic triaxial test, dynamic shear modulus, damping ratio, Izmir-Turkey

ABSTRACT: Recently, testing of both cohesive and granular soils became the focus of research especially for the dynamic behaviour of local soils. When dynamic soils properties are concerned, dynamic shear modulus and damping ratio are the most important parameters to define the behaviour of soils. With this object, soil samples derived from three deep boreholes in the northern part of İzmir – Turkey, are subjected to dynamic loadings to investigate the dynamic properties of soils by means of cyclic triaxial tests. Dynamic shear modulus and damping ratio with accordance to deformation level are evaluated. Besides, these parameters are also interpreted by some empirical relationships by using the standard penetration resistance and index properties of soil samples. Data achieved from cyclic triaxial tests and empirical formulations are found to be somewhat different from each other. This is thought to be a result of disturbance of soil samples in deeper elevations, as it was not possible to have undisturbed samples at these locations. Equivalent-linear earthquake site response analyses are performed for three borehole locations. The results of dynamic analyses are presented and discussed.

1 INTRODUCTION

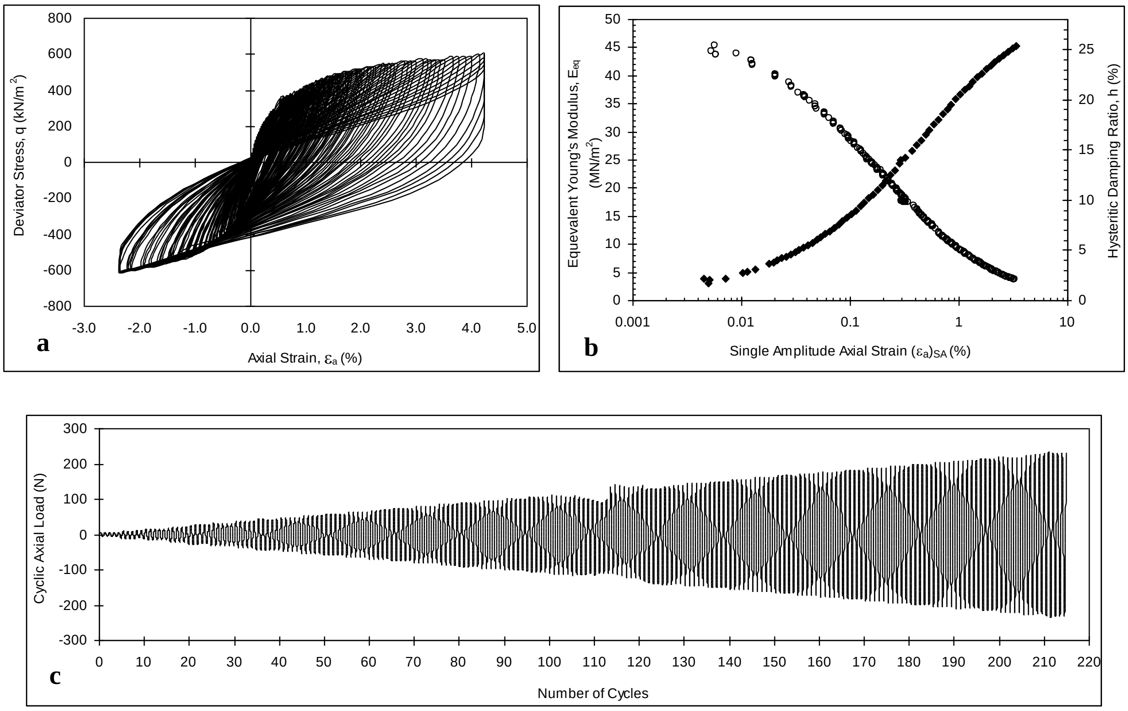
Evaluation of strain dependent dynamic properties of soils such as dynamic shear modulus and damping ratio are very important in the analysis and design of dynamically loaded structures. The measurement of these dynamic properties is a critical task in the solution of geotechnical earthquake engineering problems. To establish a reliable relationship between dynamic properties and shear strain of soils, it is necessary to know the dynamic properties from low shear strain level to high shear strain level (10^{-4}–1%). A wide variety of laboratory and field techniques are available, among them cyclic triaxial test has been the most commonly used test for measurement of dynamic soil properties at high strain levels. Many studies both on cohesive and granular soils have been performed in literature (Alarkon-Guzman et al. 1988, Yoshimine & Ishihara, 1988, Lanzo et al. 1997, Lo Presti et al. 1997, Hyodo et al. 1998, Dehghani et al. 1999, Ansal et al. 2001, Altun 2003, Wichtmann et al. 2005, Zhou & Chen 2005, Bian & Shahrour 2009).

In this study, in order to investigate the above mentioned dynamic behaviour of local soils, a pilot study area located at the northern bay of Izmir is chosen. Three boreholes named as 06_BOS, 12_MVS, and 10_KSK are identified as deep boreholes of three districts in the northern coast of Izmir Bay (Figure 1). 17 cyclic dynamic tests are performed on the undisturbed and reconstituted samples with varying soil types. Each sample is a representative of the governing soil type in the layered soil column.

Figure 1 Borehole locations in the study area.

2 TESTING PROCEDURE AND RESULTS

A series of strain controlled undrained cyclic triaxial tests has been carried out on isotropically consolidated specimens at a frequency of 0.1 Hz to evaluate the dynamic properties of soils. The specimens had a diameter of 5 cm and a height of 10 cm. Undisturbed soil samples were achieved in relatively shallow depths, but reconstituted samples were prepared by air pluviation method for deep elevations. To investigate the stress-strain relations in soils at low deformation levels, cyclic loading was applied to specimens continuously and at every five cycles, stress amplitude increased to determine dynamic soil properties. In these tests, the stress amplitude started from very small values and increased at every five cycles, deformation was observed not to exceed the elastic boundaries and experiments have been carried out until a certain number of cycles are reached.



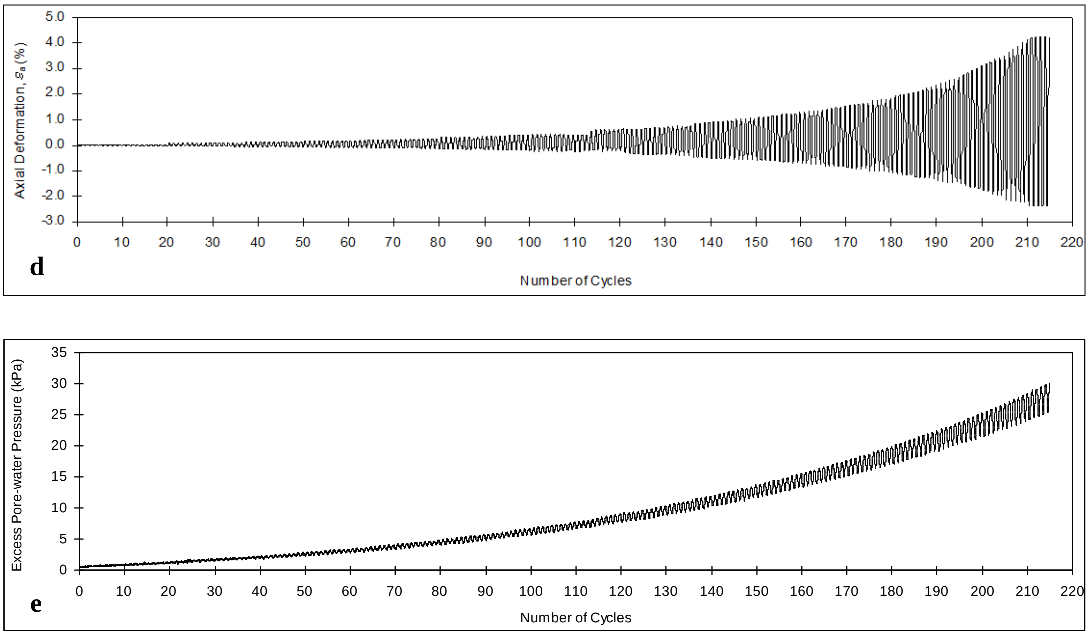


Figure 2. (a-e) Cyclic triaxial test results of a clay specimen of 10_KSK borehole.

Cyclic stress-strain curves (hysteresis loops), shear modulus and damping ratio, variation of cyclic axial load, axial deformation and excess pore-water pressure with number of cycles for a clay specimen (31.75 m) of 10-KSK borehole is presented in Figure 2 (a-e), respectively. The stress-strain values at the fifth cycle of each five cycles are taken into consideration when drawing the shear modulus and damping ratio curves.

The results of cyclic triaxial tests are gathered in Table 1. Maximum shear modulus of each soil sample with varying depth is given in Table 1 for three boreholes.

Table 1. Maximum shear modulus of the samples

Borehole Name	Depth (m)	Soil Type	Sample Type	σ_v' (kPa)	G_{max} (MPa)
06-BOS	15.25	Silty clay	UD	58	110
	31.75	Gravelly clay	UD	119	252
	42.00	Gravelly silty clay	UD	162	328
10-KSK	13.25	Clay	UD	50	69
	22.75	Gravelly clay	UD	79	145
	31.75	Clay	UD	111	127
	42.25	Silty clay	UD	147	276
	97.00	Clayey silt	RC	390	346
	122.00	Gravelly clay	RC	480	367
12-MVS	7.50	Silt	UD	50	49
	18.25	Clay	UD	90	92
	24.25	Silty clay	UD	100	142
	55.75	Clayey silty sand	RC	300	152
	90.00	Sandy clayey silt	RC	400	324
	118.00	Gravelly clay	RC	500	372
	154.00	Gravelly clay	RC	600	454
	226.00	Gravelly clay	RC	800	754

3 NUMERICAL ANALYSES

Before stepping into one dimensional dynamic analysis of soil columns in three locations, dynamic site-response parameters were also calculated empirically. Therefore a comparison between the laboratory data and calculated data would become available. For the evaluation of maximum shear modulus, proposed relationships of Seed & Idriss (1970), Ohta & Goto (1976), Imai & Tonouchi (1982), Gazetas, (1983) or Hardin (1978) were preferred according to the type and properties of soil layers. The results of calculated maximum shear modulus are given in Table 2. Damping ratio of granular and cohesive soils was also calculated using Ishibashi & Zhang (1993) relationship.

Table 2. Maximum shear modulus calculated by empirical models

Borehole Name	Depth (m)	Soil Type	G_{max} (MPa) (Calculated)
06-BOS	15.25	Silty clay	70
	31.75	Gravelly clay	142
	42.00	Gravelly silty clay	355
10-KSK	13.25	Clay	63
	22.75	Gravelly clay	102
	31.75	Clay	125
	42.25	Silty clay	212
	97.00	Clayey silt	554
	122.00	Gravelly clay	621
12-MVS	7.50	Silt	61
	18.25	Clay	93
	24.25	Silty clay	107
	55.75	Clayey silty sand	225
	90.00	Sandy clayey silt	509
	118.00	Gravelly clay	733
	154.00	Gravelly clay	806
	226.00	Gravelly clay	1020

The one dimensional dynamic site-response analyses applied in this study is based on an equivalent linear model. In this model, the linearity assumption allows development of efficient computational models to perform dynamic analysis. The parameters maximum shear modulus (G_{max}) and damping ratio (ξ) are referred to as equivalent linear parameters of the soil material. These parameters are used to describe the dynamic behaviour of soils for site response analysis. Degradation of the modulus ratio G/G_{max} with shear strain is calculated, and resulting modulus reduction curve is taken into consideration in the dynamic analysis (Kramer, 1996).

Information of soil type, thickness, total unit weight, maximum shear modulus and ground water level were defined with the help of borehole data. The modulus reduction curves (G/G_{max}) and damping ratio values for each SPT-depth of soil profile were calculated for shear strains varying between 0.0001 and 10 percent for model tests. The soil profiles were constituted in a similar manner with the data obtained from laboratory tests.

The soil columns were subjected to a scenario earthquake with a magnitude of 6.5 occurring on the closest critical source named as Izmir Fault. The acceleration history of 1977 Izmir Earthquake was used and scaled to generate the scenario earthquake. The dynamic site-response analysis results are presented in Table 3.

In Table 3, a_s is the maximum ground surface acceleration (g), a_r is the maximum bedrock acceleration (g), a_s/a_r is the acceleration ratio, S_{as} is the maximum spectral acceleration on ground surface, S_{ar} is the maximum spectral acceleration on bedrock, and S_{as}/S_{ar} is the spectral acceleration ratio.

Table 3. Results of dynamic site-response analyses for scenario earthquake

a_s (g)	a_r.(g)	a_s/a_r	S_{as} (g)	S_{ar} (g)	S_{as}/S_{ar}	a_s (g)	a_r.(g)	a_s/a_r	S_{as} (g)	S_{ar} (g)	S_{as}/S_{ar}
MODEL-06BOS						*LAB-06BOS*					
0.369	0.300	1.23	1.2183	1.0191	1.20	0.398	0.300	1.33	1.3189	1.0191	1.29
MODEL-10KSK						*LAB-10KSK*					
0.337	0.300	1.12	1.7832	1.0191	1.75	0.439	0.300	1.46	1.8869	1.0191	1.85
MODEL-12MVS						*LAB-12MVS*					
0.353	0.300	1.18	1.6477	1.0191	1.62	0.273	0.300	0.91	1.1201	1.0191	1.10

4 CONCLUSIONS

Soil samples derived from three deep boreholes in the northern part of Izmir – Turkey, are subjected to dynamic loadings to investigate the dynamic properties of soils by means of cyclic triaxial tests. Dynamic shear modulus obtained by cyclic triaxial tests and the ones interpreted by some empirical relationships by using the standard penetration resistance and index properties of soil samples are found to be somewhat different from each other. As the tests were performed with conventional measurements, it was not possible to measure maximum shear modulus for very small strains. Second part of this study will be evaluating dynamic soil properties using bender elements for small strain levels. The disturbance of soil samples in deeper elevations is thought to be another concern for this study. The difference may be due to the preparation of soil specimen, being undisturbed or reconstituted. Equivalent-linear earthquake site response analyses showed that soil columns constituted with laboratory data generally resulted in higher dynamic soil parameters. Especially, the amplification on ground surface could be different. It is concluded that model studies should be supported by laboratory tests in order to achieve reliable results of soil behaviour under dynamic loadings.

ACKNOWLEDGEMENTS

This study is a part of TUBITAK Project 106M013 “Evaluation of dynamic soil properties in the northern coast of Izmir Bay”. The authors are grateful to TUBITAK for the financial support.

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